Rare K Decays: E949 and KOPIO

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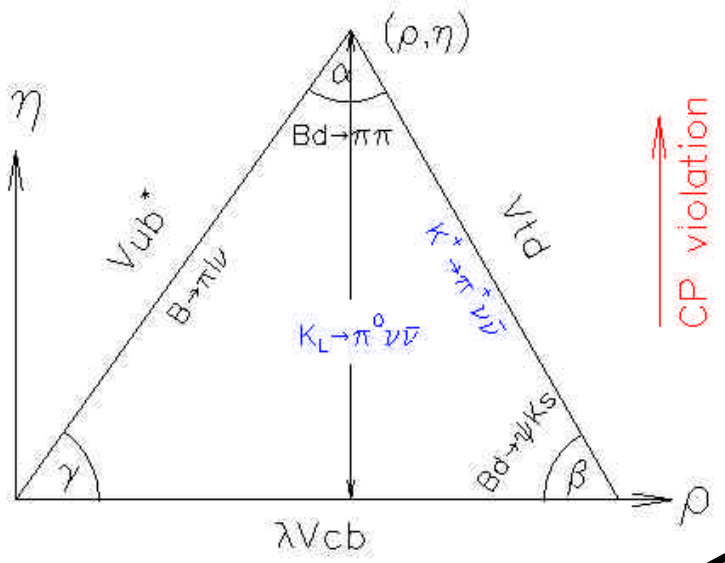
DOE Review of BNL April 22, 2003

Standard Model CP Violation



$$\left\{ \text{"Jarlskog invariant"} \ |J_{CP}| \right.$$
$$\left. 2A_{\Delta} = \left| \mathrm{Im} V_{ts}^{*} V_{td} \right| l \left(1 - \frac{l^2}{2} \right) \right\}$$

Four special processes will challenge the Standard Model:

$K_L^0 \to p^0 n \bar{n}$	$\mathrm{Im}(V_{ts}^{*} V_{td})$	KOPIO
$K^+ \to p^+ n \bar{n}$	$\lvert V_{ts}^{*} V_{td} \rvert$	E949, CKM
$B_d \to y K_S$	$\sin(2b)$	BABAR, BELLE, CDF, D0
$\frac{x_s}{x_d}$	$\left\lvert \frac{V_{ts}}{V_{td}} \right\rvert$	CDF, D0, LHCB, BTEV

The Roles of E949 and KOPIO in Flavor Physics

New flavor physics in the s-d sector may be very different from that in the b sector:

* *If B - physics is consistent with the SM*:

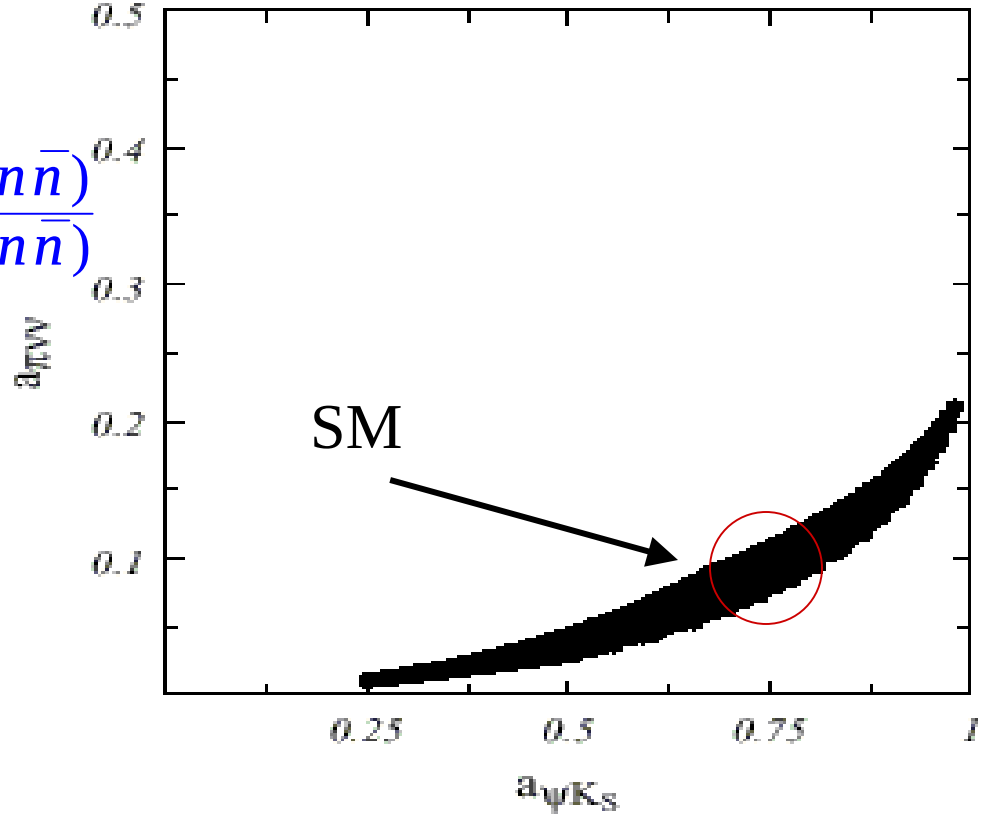
*N*ew physics could be revealed $K \to p n \bar{n}$.

* *If deviations from the SM are indicated* :

$K \to p n \bar{n}$ would add crucial additional information; the complexity of the flavor sector beyond the SM is foreseen in many models.

$\mathbf{B} \to y\, K_S$ *and* $\mathbf{K} \to p\, n\, \bar{n}$

$$\frac{\Gamma(\mathbf{K}_L^0 \to p^0 n\bar{n})}{\Gamma(\mathbf{K}^+ \to p^+ n\bar{n})}$$



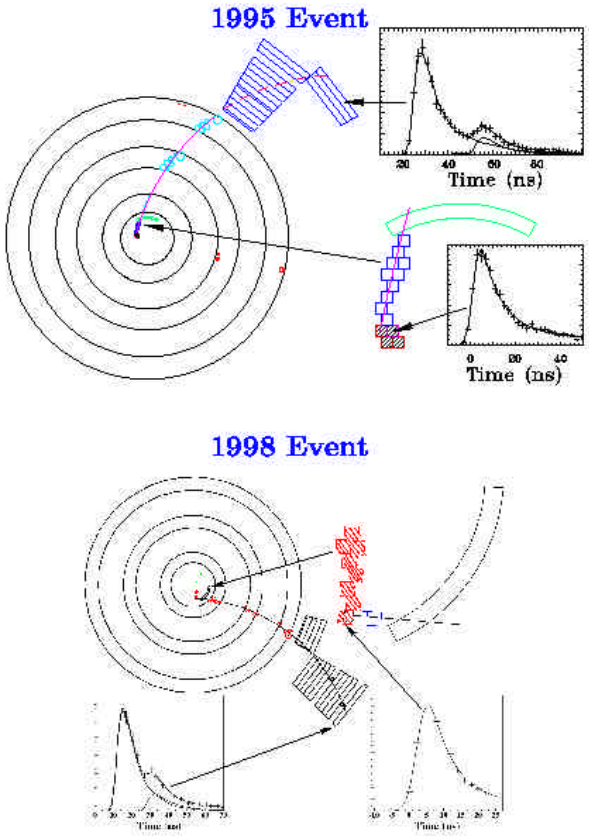
Candidates:

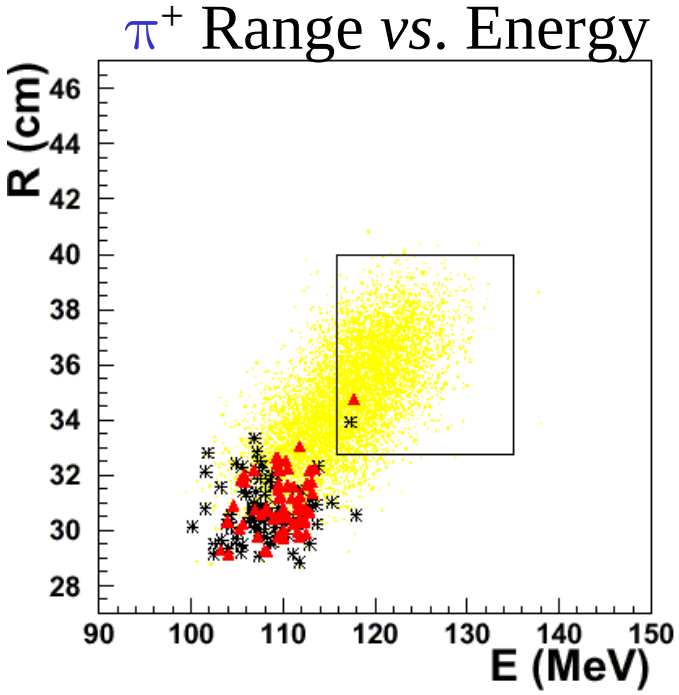
* Low energy SUSY
* Minimal Flavor Violation
* Multiple Higgs
* New Physics in $B_d - \overline{B_d}$
* New Physics in $s \to d\, n\bar{n}$
* Extra dimensions

CP asymmetry in $\mathbf{B} \to y\, K_S$

Nir and Worrah, Phys. Lett. **B423**,319 (1998)

E787 2002: *Two* $K^+ \to p^+ n\bar{n}$ *Candidates*





Branching Ratio

$$B(K^+ \to p^+ n\bar{n}) = 1.57 \pm^{1.75}_{0.82} \; x\, 10^{-10}$$

$N_{K^+} = 5.9\, x\, 10^{12}$ Efficiency $e = 2\, x\, 10^{-3}$

Estimated Background: 0.15 ± 0.05 events

D'Ambrosio and Isidori
hep-ph/0112135

Impact of $K \to p\bar{n}n$ on Flavor Physics

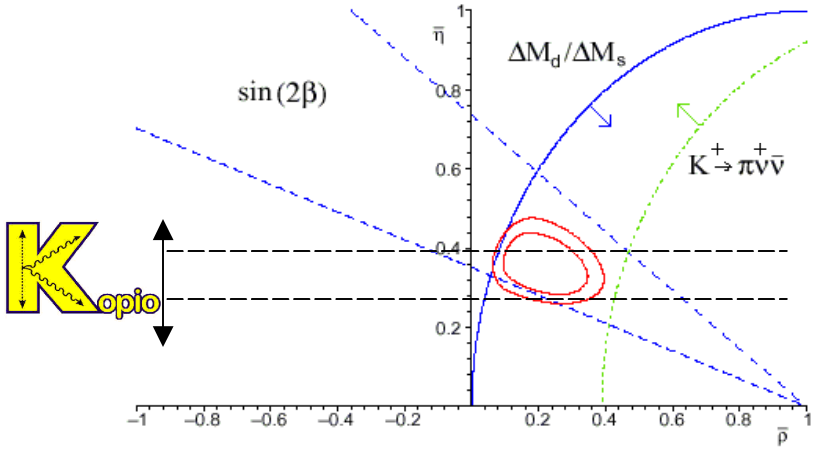


Figure 2: Allowed region in the $\bar{\rho} - \bar{\eta}$ plane using only theoretically *clean* observables: 90% C.L. interval imposed by $\sin(2\beta)$ (dashed); 90% C.L. limit from the upper bound on $\Delta M_{B_d}/\Delta M_{B_s}$ (full); 90% C.L. limit from the lower bound on $\mathcal{B}(K^+ \to \pi^+ \nu\bar{\nu})$ (dotted). For comparison the 68% and 90% C.L. ellipses from the global fit in Fig. 1 are also shown.

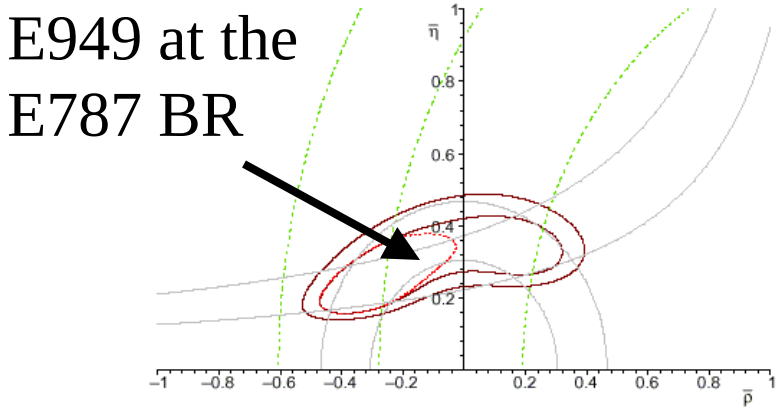


Figure 3: Allowed region in the $\bar{\rho} - \bar{\eta}$ plane with the inclusion of $\mathcal{B}(K^+ \to \pi^+ \nu\bar{\nu})$ and without B_d–$\bar{B}_d$ data. The two external contours denotes 68% and 90% confidence intervals; the inner (dotted) one is the 68% confidence interval under the assumption that experimental error in (1) is reduced by a factor two.

E787 and other clean observables (90% CL)

Possible E949 result favoring Non-SM

$K^+ \to p^+ n\bar{n}$ ***Future Prospects***

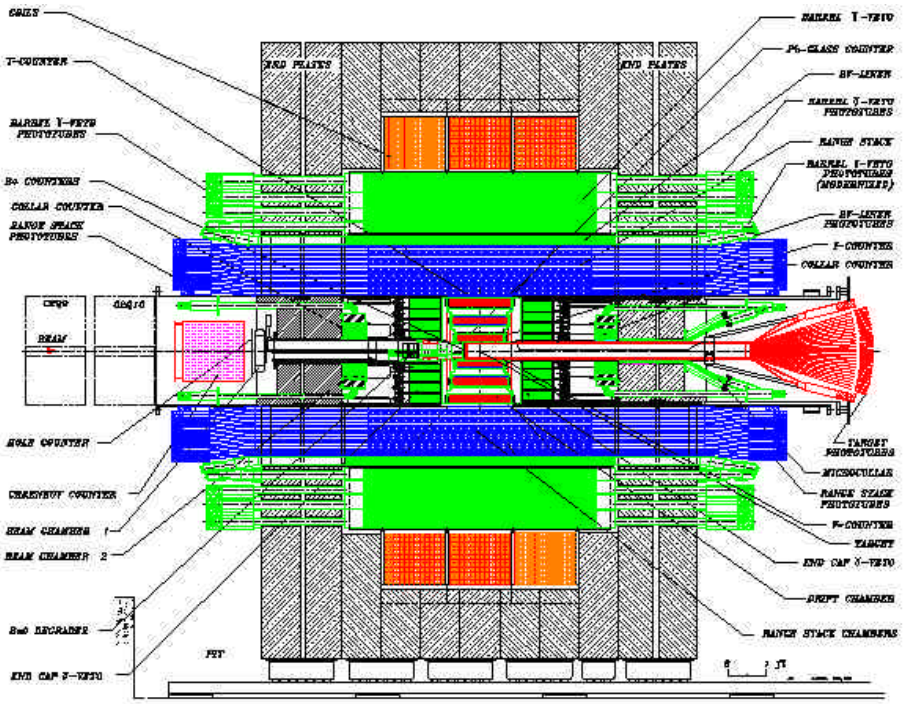
BNL *E949*

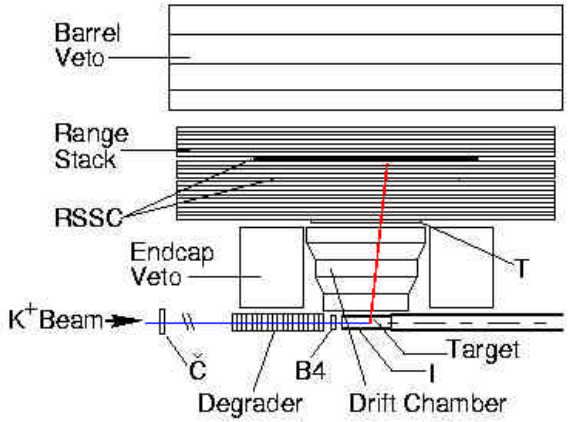
- **Upgrade of E787 detector**
  - Improved photon vetos – truly hermetic coverage
  - Access to the low momentum region
- **2002 Run:** $\leq$ *E787 sensitivity ; ~20% of E949*

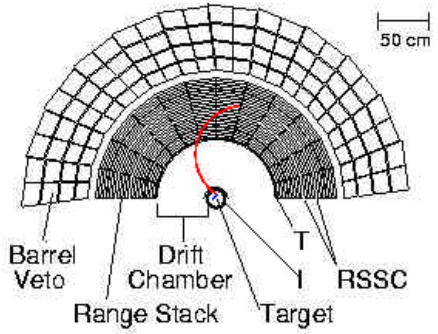
  Results : summer 2003
- **E949 Sensitivity goal**: $<10^{-11}$
  - Order of magnitude improvement beyond E787
  - Factor 10 below the SM prediction

BNL E787(E949)

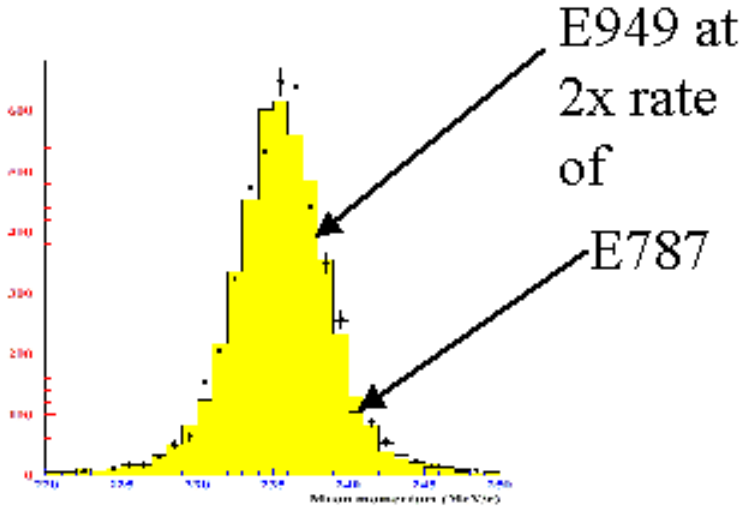
Measurement of $K^+ \to p^+ n \bar{n}$



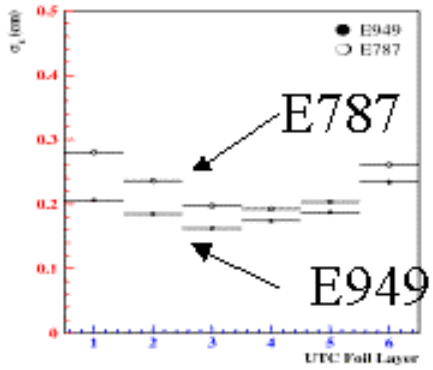




μ^+ Momentum from $K^+ \rightarrow \mu^+ \nu$

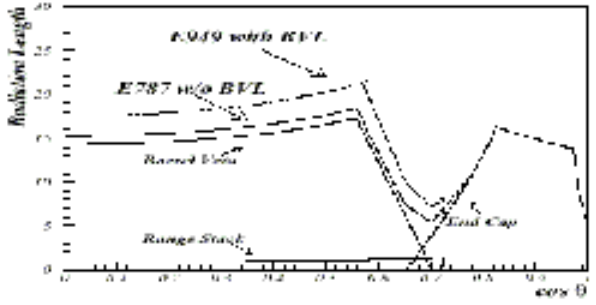


Improved UTC σ_Z



Range Stack Straw Chamber tracking Improved by 5 x

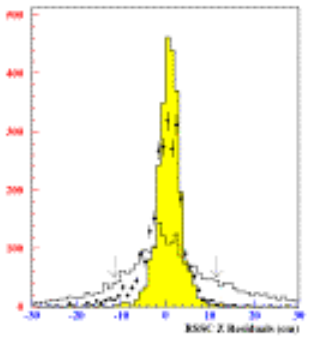
E949 Photon Veto Upgrade



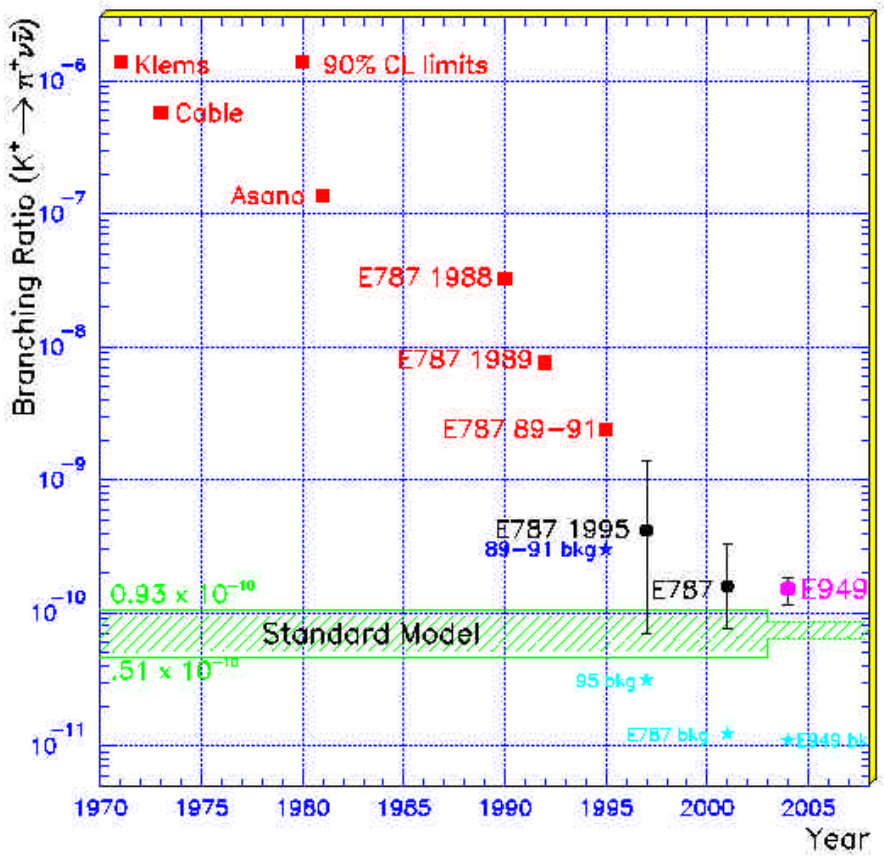
Preliminary:

2.3 x better

π^0 Efficiency



$K^+ \to p\,^+ n\bar{n}$ Measurements vs. Year



	E787	E949
Sensitivity	$0.8\ 10^{-10}$	$0.08-0.15\ 10^{-10}$
Est. Bkg. (events)	0.15	0.8

Experiments seeking $K_L^0 \to p^0 n\bar{n}$

- Limit from $K^+ \to p^+ n\bar{n}$: $< 1.7\, x 10^{-9}$ [*Grossman, Nir*]
  - KTEV (FNAL) result:

$$B(K_L^0 \to p^0 n\bar{n}) \equiv \frac{\Gamma(K_L^0 \to p^0 n\bar{n})}{\Gamma(K_L^0 \to all)} < 5.9\, x 10^{-7}$$

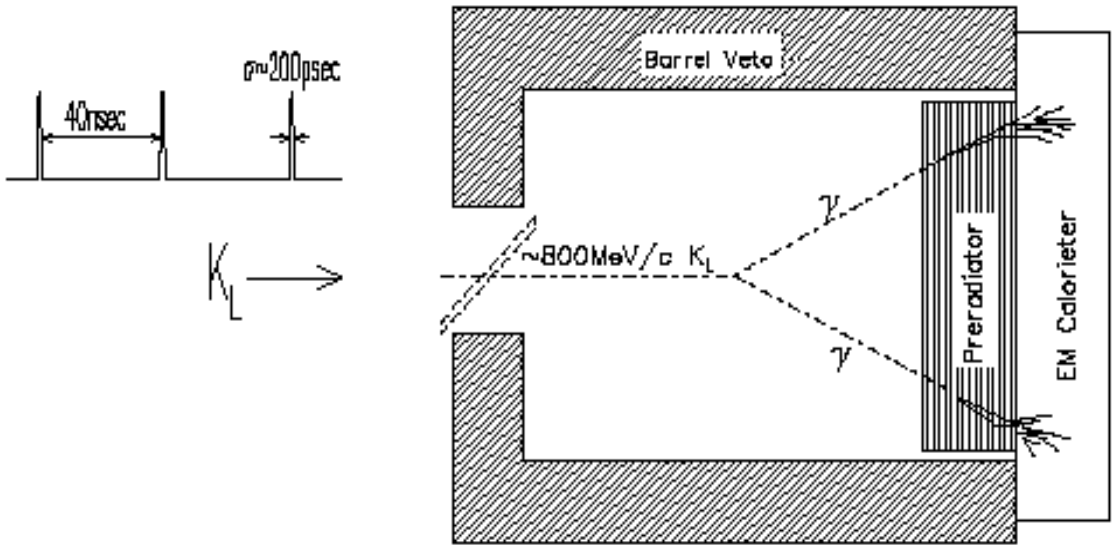
  - KEK E391a *goal* : s.e.s. $10^{-10} - 10^{-9}$
  - KOPIO (BNL) *goal* : s.e.s. $< 10^{-12}$, >50 events

Primary Background: $K_L^0 \to p^0 p^0$ $B(K_L^0 \to p^0 p^0) \sim 10^{-3}$

KOPIO: Measurement of $K_L^0 \to \pi^0 \nu \bar{\nu}$

CONCEPTS

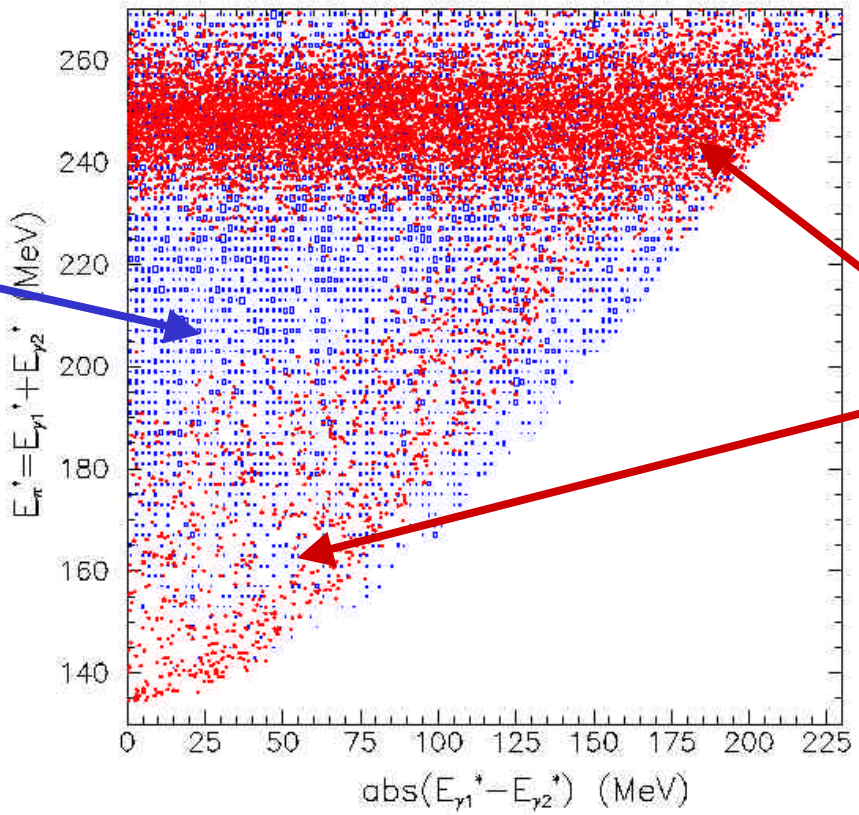
- Measure as much as possible:
  Energy, position and $ANGLE$ of each photon.
- Work in the C.M. system :
  Use TOF to get the K_L^0 momentum.
- Maximize Photon Veto Efficiency
- Maximize Intensity of Microbunched Beam



Kinematic suppression of backgrounds
Goal: >50 Events with S/N>2

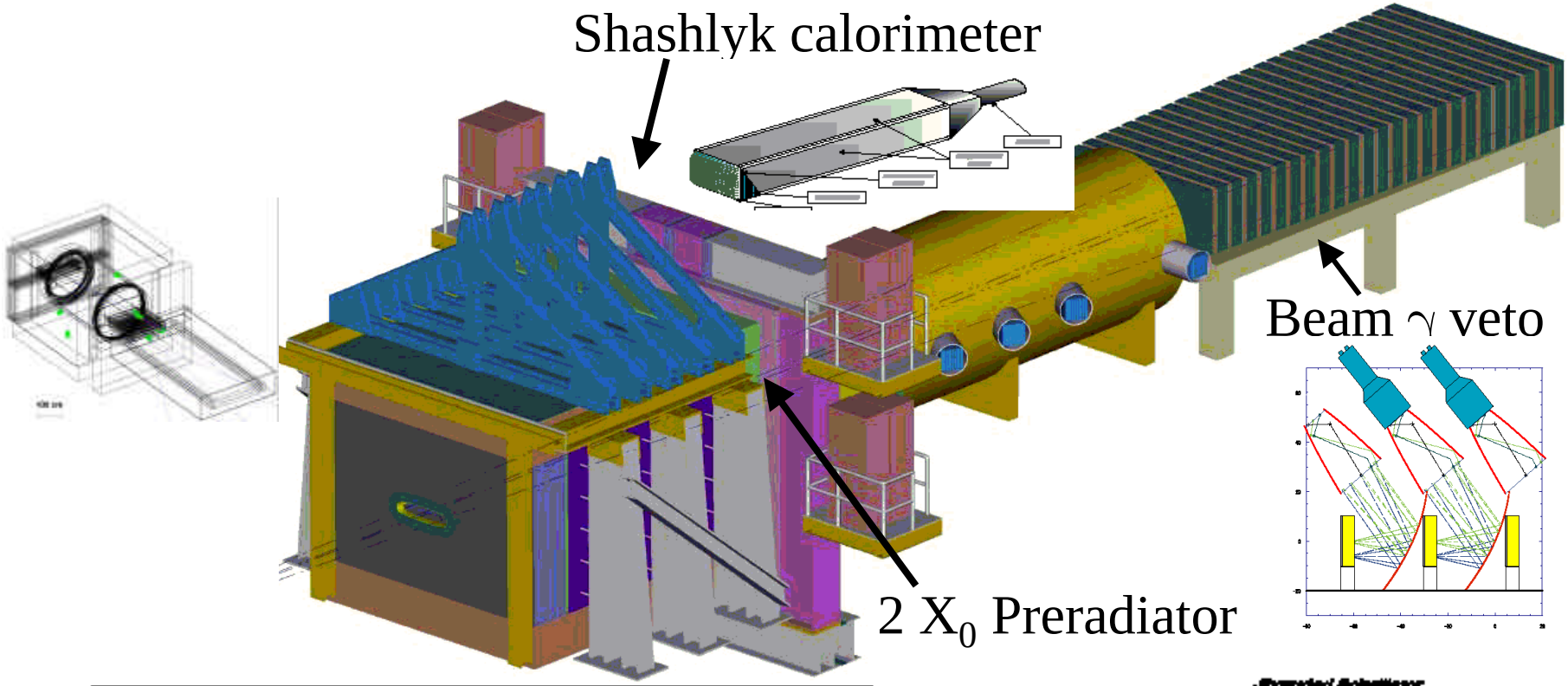
$$E^*_{p^0} \ vs. \left| E^*_{g1} - E^*_{g2} \right|$$

$K^0_L \to p^0 n \bar{n}$

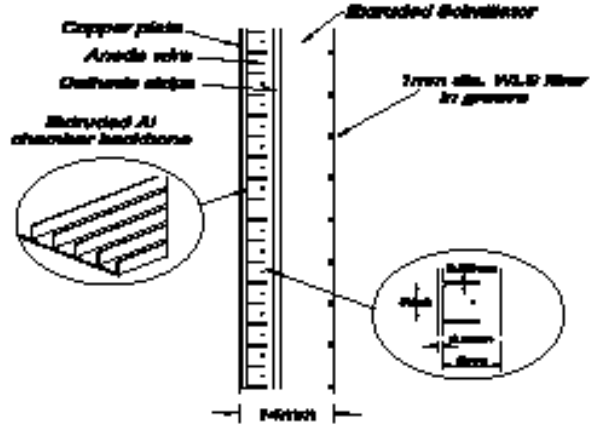


$K^0_L \to p^0 p^0$

Substantial Progress on R&D
All minimal requirements met.

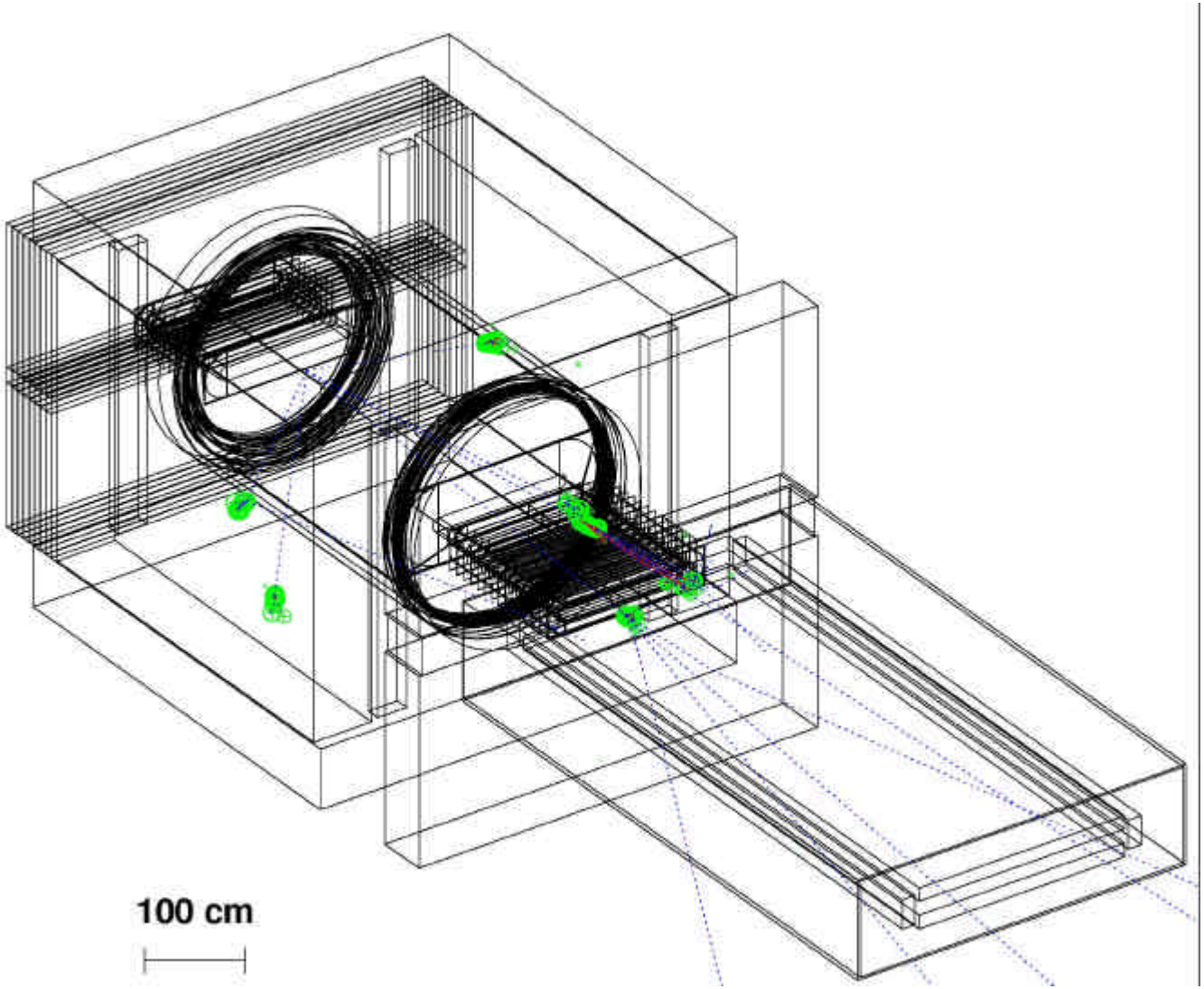


Parameter	Minimal Requirement	Expected Performance
E_γ resolution	$3.5\%/\sqrt{E}$	$2.7\%/\sqrt{E}$
θ_γ resolution (250MeV)	$(25-30)$ mr	23 mr
t_γ resolution	$100ps/\sqrt{E}$	$50ps/\sqrt{E}$
x_γ, y_γ resolution(250MeV)	10mm	$<$ 1mm
μ-bunch width	$300ps$	$200ps$
γ-veto inefficiency	$\overline{\epsilon}_{E787}$	$0.3\overline{\epsilon}_{E787}$



KOPIO Event Display

Background Event:
K_L -> 3 π^0

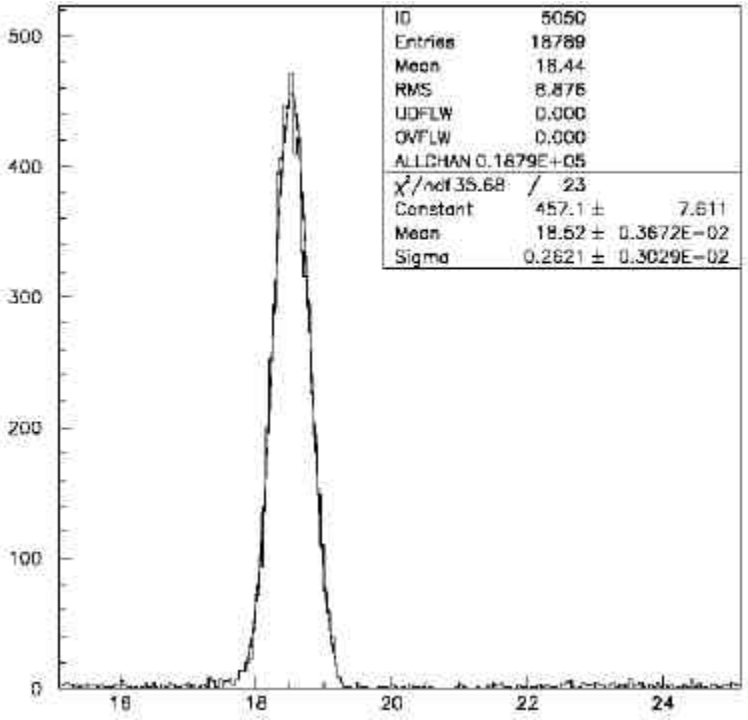


Results of the 2002 beam test

Microbunch width

Studied the RF extraction mechanism proposed for KOPIO & measured a microbunch rms width of 244 ps -- KOPIO requires a 300 ps rms

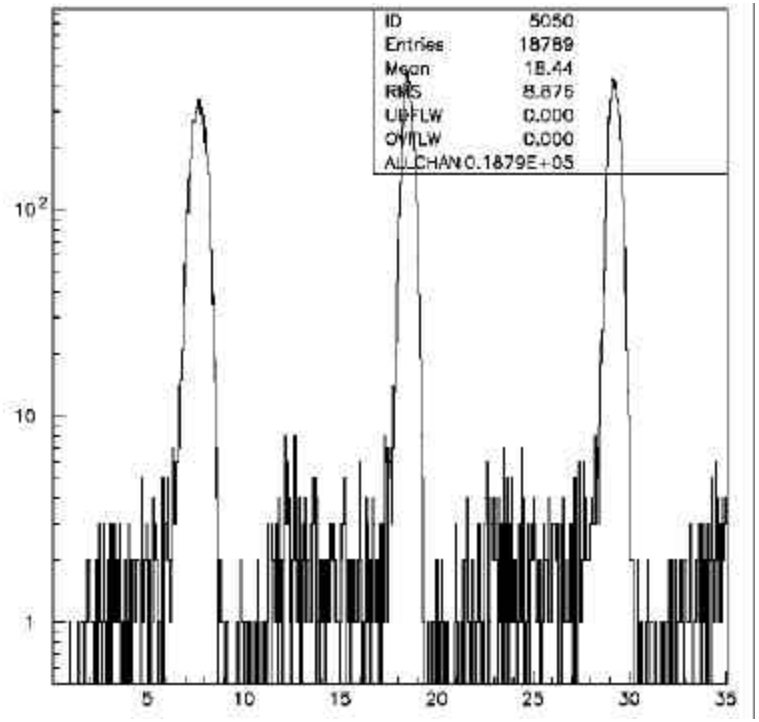
Also developed monitoring methods



Interbunch extinction

Measured the inter-bunch extinction ratio (flux between bunches/within bunch). Observed a ratio of ~3-4% (could be less) KOPIO requires ~ 10^{-3}

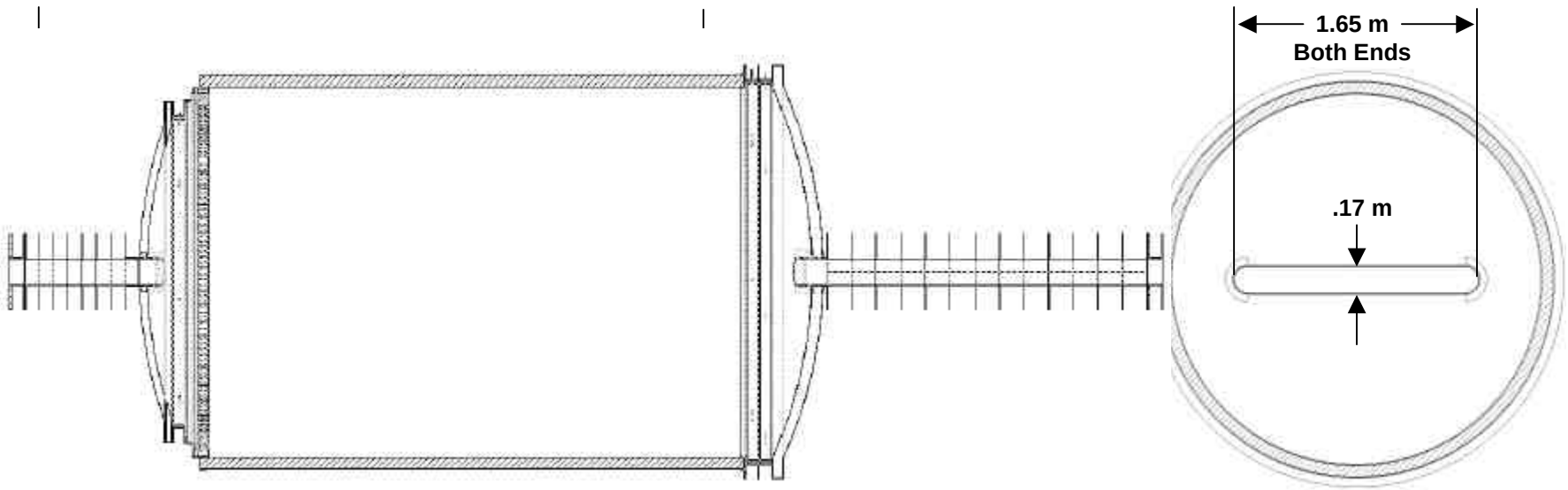
Need to control power supply ripple



Vacuum Tank Progress

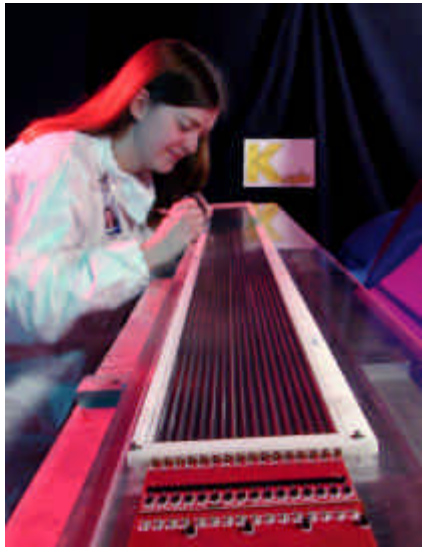
- Perform finite element analysis of critical elements
- Prepared drawings of Be beam pipes for evaluation by fabricators
- Revise 2001 design drawings to incorporate new geometry
- Prepare drawings of honeycomb structure for evaluation by fabricators

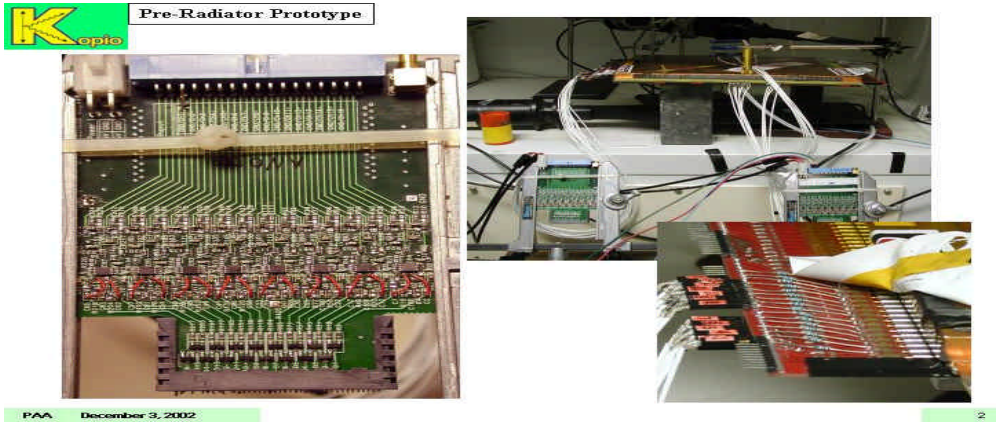
Current Design



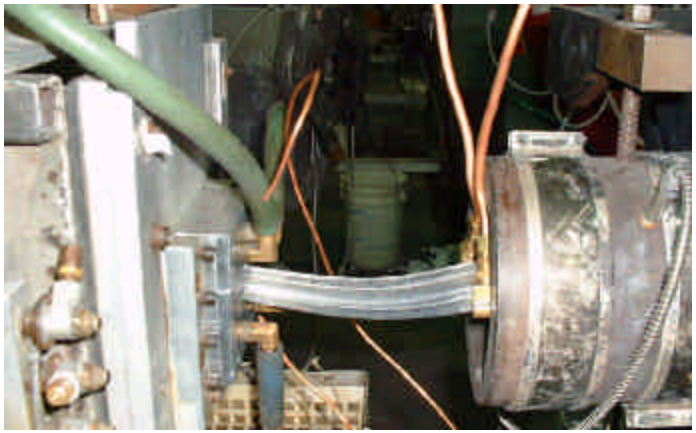
Preradiator Prototype Chambers, Electronics and Scintillators

- Tests on prototypes ongoing – resolution , efficiency measured.
- Preliminary designs for anode and cathode strip electronics
  Full Size (1 dimension) Prototypes **(**under construction**)**
- Extruded scintillator with holes under development





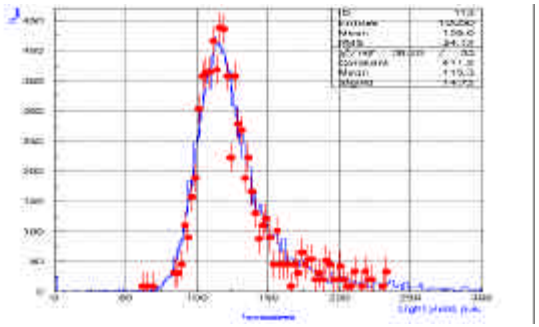
Extruded Scintillator



Calorimeter R&D

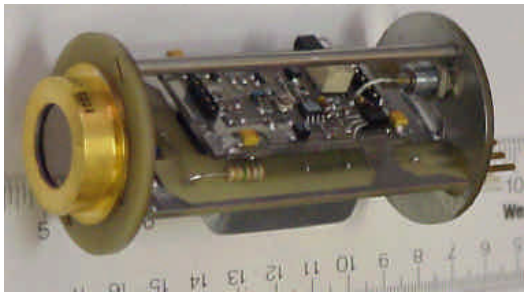
Previous work

•Established excellent MC⇔data agreement
•Demonstrated <4%/ E resolution in beam test at NSLS
•Allowed confident extrapolation to ~3%/ E



In the last 12 months

- Extensive design optimization work
- 20 production-prototype units delivered
- Cosmic ray testing is in progress
- NSLS beam tests about to begin
- APD tests well along



KOPIO COLLABORATION

- *Highly experienced in rare K decay measurements*
- *R&D in advanced stages*
    - *Well prepared for crucial design decisions*
- *6 Countries (18 Institutions, 73 Physicists)*
    - *Substantial International funding*

Ready for the challenge of construction.

Brookhaven National Laboratory I-H. Chiang, J.W. Glenn, D. Jaffe, D. Lazarus, K. Li, L. Littenberg, G. Redlinger, C. Scarlett, M. Sivertz, A. Stevens, R. Strand

University of Cinncinnati K. Kinoshita

IHEP, Protvino* G.Britvich, S.Chernichenko, R.Rogalev, V.Semenov, I.Shein, A.Soldatov, N.Tyurin, V.Vassil'chenko, A.Yanovich

INR, Moscow A. Ivashkin, *D.Ishuk*, M. Khabibullin, A. Khotjanzev, Y. Kudenko, A. Levchenko, O. Mineev, N. Yershov and *A.Vasiljev*.

INFN-University of Perugia G. Anzivino, P. Cenci, *E. Imbergamo*, A. Nappi, M. Valdata

KEK M. Kobayashi

Kyoto University of Education* R. Takashima

Kyoto University *K. Misouchi, H. Morii*, T. Nomura, N. Sasao, *T. Sumida*

Virginia Polytechnic Institute & State University M. Blecher, M. Pitt, B. Vogelaar

University of New Mexico B. Bassalleck, N. Bruner, D.E. Fields, J. Lowe, T.L. Thomas

University of Montreal* J.-P. Martin

Thomas Jefferson National Accelerator Facility M. Ito

State University of New York at Stony Brook *I. Christidi*, M. Marx, D. Schamberger

TRIUMF P. Amaudruz, E. Blackmore, A. Daviel, M.Dixit, J. Doornbos, P. Gumplinger, R. Henderson, J. Macdonald, T. Numao, R. Poutissou

University of British Columbia D. Bryman, M. Hasinoff

University of Virginia E. Frlez, D. Pocanic

University of Zurich P. Robmann, P. Trüol, A. van der Schaaf, *S. Scheu*

Yale University G. Atoyan, S.K. Dhawan, V. Issakov, H. Kaspar, A. Poblaguev, M.E. Zeller

** New institution since last review. Grad students*

KOPIO International Funding Plan (M$)*

	R&D	Construction
US	1.4 (pending: 5)	58
Canada	0.5	11†
Italy	0.1	1#
Japan	0.1	2
Switzerland	0.1	0.6
Russia	In kind	In kind

† Plus CFI -LADD funding for detector infrastructure

* **Excludes much scientific manpower.** # **Possible contribution**.

Approved 4/2002: C$7.2M

Contingent on NSF KOPIO funding

KOPIO CFI International Access Fund

Goal: To collaborate with BNL to **upgrade the AGS** to deliver 10^{14} protons/pulse (100 Tp) with microbunching

***UBC**-TRIUMF Activities:*

Beam dynamics microbunching & space charge

Extraction/injection kicker upgrades

25 MHz radiofrequency cavity/amplifier

US Funding Situation

E949

- **DOE**
  - No AGS HEP in FY2003, 2004
  - HEPAP endorsement of E949 Physics
- **NSF**
  - Inclusion of **E949** in **RSVP** program is possible
  - ***Separate E949 Proposal*** *prepared (FY2003-5)*

KOPIO

- **NSF**
  - R&D supported (Yale, Stony Brook)
  - **RSVP** (KOPIO and MECO) – top rated.
  - **RSVP** funding plan in FY2004 President's Budget

- **DOE**
  - RHIC operations – agreement with NSF
  - University, BNL group support must continue

RSVP Construction start: FY'06

(Trying for an earlier start…)

$218M including MRE, R&D, Operations

KOPIO/MECO (40/60% MRE)

5-year construction period

***Annual* post-construction operations:**

$15M

E949

Summary and Outlook

E949 and KOPIO are poised to make crucial contributions to quark-mixing and CP violation.

Program threatened by lack of support for BNL personnel.

***Future of E949 uncertain* – a major investment may be squandered and an important scientific advance lost.**

An Official RSVP Funding Plan Now Exists

KOPIO *will increase its readiness for full construction.*

R&D on beams and detectors has been successful.

- Clear paths to final design decisions exist.
- Tentative arrangements for construction have been set.
- Collaboration (strong and growing) can now solidify.

  New collaborators, post-docs, and students are anticipated.
- Substantial international funding is anticipated.